NASA TECHNICAL TRANSLATION NASA TT F-11,605

NASA TT F-11,605

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Translation of "Vliyaniye Razlichnykh Pit'yevyky Rezhimov na Diurez v Usloviyakh Vysokoy Temperatury Vozdukha i Fizicheskoy Nagruzki"
Fiziologicheskiy Zhurnal SSSR imeni I. M. Sechenova, Vol. 49, No. 10, pp. 1249-1253, 1963

GPO PRICE $ _____

CSFTI PRICE(S) $ _____

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

N68-19802

(ACCESSION NUMBER) (THRU) 1

8 (PAGES) (CODE) 04

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

FACILITY FORM 602

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1968

EFFECT OF VARIOUS DRINKING PATTERNS ON DIURESIS UNDER HIGH AIR TEMPERATURE AND PHYSICAL STRESS CONDITIONS

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ABSTRACT. Tests were made to find the effect of heat and work on diuresis for three drinking patterns. Diuresis decreased with each hour in all tests for all drinking patterns, while the specific gravity increased. Losses from the skin and lungs were about 4.7% of the average body weight. Dehydration, caused chiefly by heavy perspiration, affects diuresis, but the main cause of reduced diuresis is reduced blood supply to the kidneys. Economization of water by reduced diuresis is only about 5% of total water losses. Diuresis did not differ greatly for the various drinking patterns. Anuria was not observed.

During light work in a temperate climate about half of the water expelled by the human organism is discharged with urine. In a hot climate, or under high external temperature conditions in general, these relations shift toward increasing extrarenal water losses, primarily as a result of perspiration. /1249*

Many authors have established that diuresis in people decreases during heavy perspiration caused by high external temperature (Kassirskiy, 1929; Solov'yev, 1934; Mittel'shtedt, Severin, 1934' Adol'f, 1952; Kanter, 1955), and some of them (Kassirskiy, 1929; Bogdanov, Khozak, 1929; Solov'yev, 1934) noted anuria (even during the consumption of water). E. Adol'f, on the other hand, asserts that he did not observe anuria in people under desert conditions, even during significant dehydration of the body.

A decrease in diuresis under conditions of great heat stress caused by the high temperature of a surrounding medium, as well as by physical work, is evidence of the body's economy of water, which is largely expended in the formation of perspiration. The following questions arise: To what extent can water be economized as a result of decreased diuresis? What effect does a given drinking pattern have on the dynamics of the discharge of urine? Is it possible to judge the extent of dehydration of the body on the basis of the amount of diuresis? We conducted tests in a heat chamber to find the answers to the above questions.

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* Numbers in the margin indicate pagination in the foreign text.

Method

Studies were conducted in a heat chamber at a temperature of 36-37° and a relative humidity of 35-40%. The air velocity did not exceed 0.1 m/sec.

All studies were conducted on healthy male subjects (Table 1).

Each test lasted for 5-6 hours. The subjects performed programmed physical work for 45 minutes of each hour (stepping upon and off a 20 cm-high box 20 times per minute to a metronome). They rested for the remaining 15 minutes. During the rest period the subjects were weighed, and their diuresis and body temperature were measured. Certain other indicators of the physiological functions and how the subjects were feeling were also recorded.

Diuresis was studied for three drinking patterns: a) Drinking when necessary, where the subjects drank water as thirst developed; b) Abundant drinking, where water was consumed in quantities sufficient for maintaining original body weight; c) Complete restriction on drinking, where the subject drank no water at all during the course of the test.

It should be noted that with the abundant drinking pattern the subjects were required to drink more water than they desired, since, under conditions of heavy perspiration, thirst lags behind the body's natural water losses (Adol'f, 1952; Kalmykov, Yeronin, 1955; Yeronin, 1961).

Salty and strong foods were eliminated from the subjects' diet on the day before and during the days of the tests.

Urine was sampled an hour before the beginning of the test, and then every hour during the stay and work in the heat chamber, for the purpose of studying the dynamics of diuresis.

Table 1

STATISTICS OF SUBJECTS

Subjects	Age (years)	Weight (kg)	Height (cm)
F	30	61	166
S	27	66	170
I	24	68	171
I	29	64	166
L	27	60	165
M	27	76	172
O	23	58	168
E	22	59	169

Water, in addition to being discharged with urine, is lost in perspiration and by evaporation from the lung surfaces. To determine water losses from the lungs, the volume of lung ventilation, which ranged from 16 ℓ to 18 ℓ/minute for the various subjects, was found. Because of the fixed absolute humidity of the heat chamber atmosphere and the fixed volume of lung ventilation, and considering that the exhaled air was saturated with water vapor, we calculated that these losses constituted between 70 and 80 grams of moisture after five hours of testing. Of the total water losses, lung losses contributed only 2.0-2.5%. /1250

The amounts of perspiration of the subjects varied from 4.5% to 5.0% of the body weight, or, in absolute terms, between 2,800 and 3,500 grams, after five hours work in the chamber.

The water metabolism balance of the subjects included oxidation water, amounting to about 400 grams after five hours of medium work. The amount of physical work performed was the same in all tests. Consequently, the quantity of oxidation water could not vary significantly in the various tests, which were conducted under identical conditions, differing only in the drinking pattern. Hence, in the comparison of two tests differing in drinking patterns, this factor remained constant, and diuresis, in comparison with controlled tests, can be altered only by the quantity of water consumed.

Results of Tests

A decrease in the value of diuresis in comparison with its original level, regardless of whether the subjects drank water in unlimited quantities or drank none at all, was a common feature of all tests.

TABLE 2. CHANGES IN DIURESIS AND SPECIFIC GRAVITY OF URINE IN TESTS WITHOUT WATER CONSUMPTION (AVERAGE DATA OF FIVE TESTS ON SUBJECT F)

Diuresis Indicators	1 Hour Before Test	Hours From Start of Test					Total For Test
		1st	2nd	3rd	4th	5th	
Amount of Urine (ml)	32	30	25	23	17	11	106
Specific Gravity	1.020	1.024			1.028		

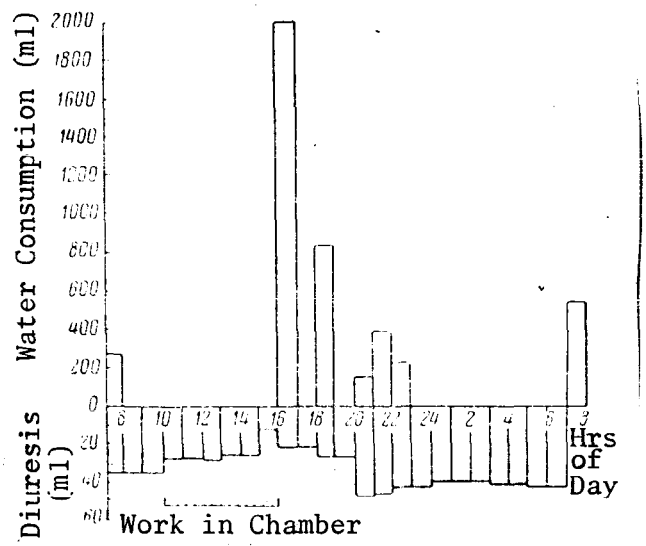
The data in Table 2 shows that diuresis was reduced with each consecutive hour during the test in which no water was consumed, and the amount of urine produced during the last hour of the test was only one third of that produced during the hour prior to the beginning of physical activity in the heat chamber. Water losses from the skin and lungs during these tests averaged 2,900 grams per subject, or about 7% of the total water contained in the body. The reduction in the amount of urine was accompanied by an increase in its specific gravity, the value of which reached the upper limits of the concentration capacity of the kidneys (Konradi, 1954).

TABLE 3. WATER CONSUMPTION AND DIURESIS IN THE HOURS FOLLOWING EMERGENCE FROM HEAT CHAMBER (STAY IN CHAMBER LASTED FROM 0930 TO 1430)

Indicators of Water Balance	Hours of Day			
	14.30—17	17—21	21—24	0.0—8
Water consumption (in ml)	2000	925	250	—
Average quantity of urine per hour (in ml)	16	32	38	28

The study of diuresis during the following hours of the day (Table 3) showed that the amount of urine produced per unit time during the first two and a half hours was about half the original quantity, despite the large quantity of water consumed after emergence from the heat chamber. Urine began to be produced in normal quantities only after 3-4 hours subsequent to emergence from the heat chamber, after the consumption of a large amount of water. The subject generated an average of 766 ml of urine per day, whereas his diuresis varied from 1000-1200 ml/day during normal days. /1251

The data furnished by certain authors concerning the occasional attacks of anuria under hot climatic conditions prompted us to conduct the six-hour test with physical work in a chamber without the consumption of water. It should be noted that the execution of this test required great stamina on the part of the subject, inasmuch as he began to experience severe thirst and dryness in the mouth, and weakness toward the end of the test.



Effect of Complete Restriction on Water Consumption During Physical Work in Heat Chamber, and of Water Consumption After Emergence from Heat Chamber, on Dynamics of Diuresis.

The graph shows that anuria did not occur (12 ml of urine was produced during the last hour) in spite of the great degree of dehydration, where water losses from the skin and the lungs constituted 5.33% of the original body weight (or 8% of the total water contained in the body). It is characteristic that during the first two hours after emergence from the chamber the generation of urine increased insignificantly, in spite of the large quantity of water consumed, and diuresis increased only in the fourth or fifth hour after emergence from the chamber, and then only slightly exceeded its original level. The daily discharge of urine was 760 ml. During ordinary days the diuresis of the subject was about 1,000 ml. Similar results were obtained for the other six subjects (Table 4).

Table 4 shows that, as in the above tests, diuresis decreases with each consecutive hour of work in the chamber. Water losses from the skin and lungs during the five-hour stay in the chamber were 4.6% of the average body weight of the subjects, or 2,975 g. Not one case of anuria was observed.

TABLE 4. AVERAGE AMOUNT OF URINE PRODUCED DURING PHYSICAL WORK IN HEAT CHAMBER IN TESTS WITHOUT WATER CONSUMPTION (AVERAGE DATA OF 15 TESTS)

Amount of Diuresis	One Hour Before Test	During Work in Chamber Each Hour					First Hours After Leaving Chamber		
		1st	2nd	3rd	4th	5th	1st	2nd	3rd
Quantity of Urine (in ml)	33	25	23	24	20	17	27	26	34

The subjects were permitted to drink all the water they desired after leaving the heat chamber, whereupon, in the first hour after completing the work, they consumed half or somewhat more than half of that quantity of water which they lost while working in the chamber. The original diuresis, as /1252
seen in Table 4, was established only in the third hour after emergence from the heat chamber.

The study of diuresis for the drinking pattern in which water is consumed to satisfy thirst showed that its nature differs little from that of diuresis for the complete restriction on drinking (Table 5).

TABLE 5. DIURESIS FOR CONSUMPTION OF WATER AS NEEDED (AVERAGE DATA OF 10 TESTS ON 6 SUBJECTS)

Amount of Diuresis	Hour Before Test	Time from Beginning of Test in Hours					Total for Test
		1st	2nd	3rd	4th	5th	
Quantity of Urine (in ml)	37	35	29	25	23	19	131

In these tests the five-hour water losses from the skin and lungs averaged 3,006 g, or 4.65% of the average body weight of the subjects.

In the tests where water was consumed according to needs the subjects, while they worked, drank half or somewhat more than half of the amount of water which they lost through perspiration and urine, i.e. the body experienced a constant deficit of water, and this deficit increased with each consecutive hour, reaching a maximum toward the end of the work in the chamber.

The deficit of water in the body and, consequently, the increased colloidal-osmotic pressure of the blood (Kravchinskiy, 1958), is one of the factors of the reduction of diuresis during muscular work. Dehydration, however, is not the sole cause of reduced generation of urine during work. This is verified by tests with abundant drinking, where the body did not experience dehydration, although diuresis was still reduced (Table 6).

TABLE 6. AVERAGE QUANTITY OF URINE PRODUCED BY SUBJECTS DURING ABUNDANT DRINKING (DATA OF 13 TESTS ON 5 SUBJECTS)

Amount of Diuresis	Hour Before Test	Time From Start of Test (hours)					Total For Test
		1st	2nd	3rd	4th	5th	
Quantity of Urine (ml)	36	43	49	42	31	26	191

During the tests with abundant drinking, water losses from the skin and lungs were practically the same as those in the tests with the consumption of water according to need and without water. These losses constituted 4.7% of the average body weight (64.2 kg), or 3,017 g.

The primary cause of reduced diuresis during muscular work under high air temperature conditions is apparently the reduction in the supply of blood to the kidneys resulting from the redistribution of blood. In this case, most of the blood circulated through the peripheral tissues (in the muscles and skin). The kidneys, consequently, are supplied with less blood with a relatively deficient oxygen supply. Hypoxemia, as was established by A. G. Kuznetsov (1940), causes a reduction in glomerulus filtration and an increase in readsorption.

According to the data of R. O. Feytel'berg (1941) and E. A. Asratyan and D. M. Gzgzuan (1932), the reduced diuresis observed at the beginning of muscular work is caused principally by the reduction in glomerulus filtration.

The information furnished above is thus testimony of the fact that under /1253
conditions of extremely exerted water metabolism caused by heavy perspiration the human body economizes on water by reducing diuresis, but this economy makes up only a small fraction of the quantity of water expended in the formation of perspiration. Maximum economy of water caused by reduced diuresis, as observed in the tests on subject F, amounted to 150 g, or about 5% of the total losses. It should be noted that this slight economy occurred only under conditions of significant dehydration, which causes physical weakness and reduced working capacity.

The fact that anuria did not occur, even during significant dehydration, is evidence of the fact that the elimination of nitrous metabolism products is just as important to the body as the maintaining of body temperature at a level such that the preservation of working capacity is possible.

Conclusions

1. Dehydration of the human body caused by heavy perspiration is accompanied by a reduction in the quantity of urine discharged. A reduction in diuresis, however, does not depend directly on the degree of dehydration of the body. The quantity of urine discharged by the body, even for exceedingly large water losses, was not less than 11 ml/hour.

2. The nature of diuresis during heavy perspiration depends little on the quantity and pattern of water consumption. Therefore, the extent of the water deficiency in the body cannot be judged on the basis of the quantity of urine discharged.

3. The daily quantity of urine discharged during the days of the tests with work in the heat chamber was 25-30% lower than the diuresis observed during ordinary days.

4. Water economy resulting from decreased diuresis during dehydration caused by heavy perspiration and the simultaneous restriction on water consumption constitutes a small value. It did not exceed 5% of the total amount of water lost by the body during our tests.

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Translated for the National Aeronautics and Space Administration under contract No. NASw-1695 by Techtran Corporation, P.O. Box 729, Glen Burnie, Maryland 21061